Ferroelectric/piezoelectric-diamond hybrid heterostructures for high performance MEMS/NEMS devices

Scientific Achievement

Earlier, we developed ultrananocrystalline diamond (UNCD) films that exhibit exceptional mechanical strength, chemical inertness and low friction and force of adhesion making UNCD an excellent candidate for fabrication of robust/reliable MEMS and NEMS devices.

On a parallel scientific and technological path, we also developed earlier ferroelectric/piezoelectric $Pb(Zr_xTi_{1-x})O_3$ (PZT) thin films that exhibit outstanding piezoelectric and electromechanical coupling coefficients, making it an excellent material for piezoelectrically actuated MEMS/NEMS devices.

Now, under a new LDRD program, we are developing strategies for the integration of PZT and UNCD layers to enable the development of a new generation of high-performance intelligent MEMS/NEMS devices. For the integration of PZT and UNCD layers, we used an amorphous TiAl layer, studied previously in our group, which behaves as an excellent oxygen diffusion barrier between UNCD and PZT, to prevent chemical etching of UNCD during growth of the oxide PZT layer at high temperature in oxygen. We demonstrated that a 10 nm thick TiAl barrier layer, grown by magnetron sputter deposition, is enough to act as an excellent oxygen diffusion barrier. Then, we employed metalorganic chemical deposition (MOCVD) as the method for synthesizing PZT films because it produces high quality layers with fast growth rate, excellent uniformity and outstanding step coverage. Figure 1 shows a cross section SEM picture of a PZT/Pt/TiAl/UNCD layered heterostructure produced by the deposition sequence described above. Figure 2 shows an example of an excellent polarization hysteresis loop with large remnant polarization and low coercive field, taken from the PZT thin film grown on Pt/TiAl/UNCD/Si substrate as shown in Fig. 1. We then used the focused ion beam (FIB) etching technique to fabricate PZT/UNCD cantilevers (Fig 3) and paddle resonators (Fig 4) for the applications mentioned above.

Significance

Novel MEMS and NEMS devices, including sensors and actuators represent a technological revolution similar to the microelectronics revolution of the 20^{th} century. New materials, dissimilar materials integration strategies, and fabrication processes need to be investigated and developed for these new generation of multifunctional devices. The combination of ferroelectric/piezoelectric PZT and robust UNCD layers enables a new generation of MEMS/NEMS devices. Its success will revolutionize MEMS/NEMS technologies, and produce a major impact on the manufacturing industry as well as fundamental research and development. Immediate beneficiaries of this program will be the research community and industries in the fields of medicine, defense, controls, communications, and automotive, where extensive use of MEMS/NEMS has just been initiated. A paper is in preparation.

Performers

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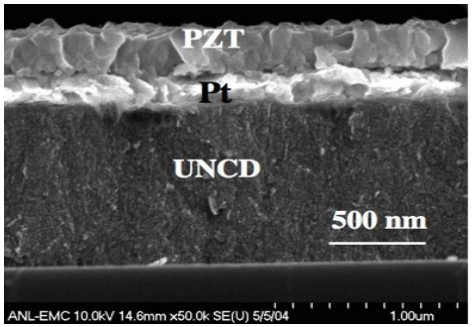


Figure 1. Cross section SEM picture of PZT thin film grown by MOCVD on a Pt (100 nm) /TiAl (10 nm) /UNCD (1 μm) layered heterostructure

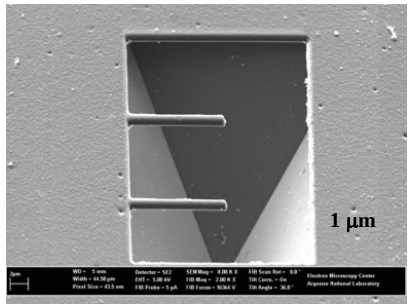


Figure 3. SEM image of UNCD cantilevers

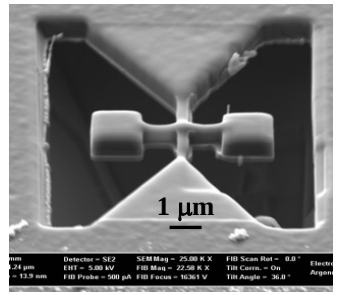


Figure 4. SEM image of UNCD paddle resonator structures

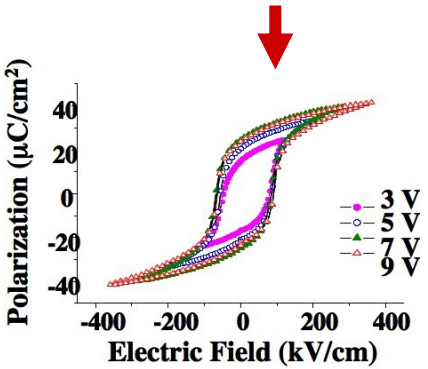
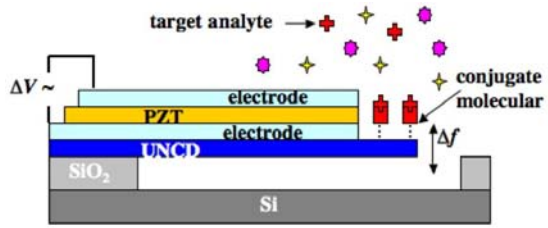


Figure 2. Characterization of first Pt/PZT/Pt/TiAl/UNCD capacitor showing excellent polarization hysteresis

Future directions:

- Optimization of processing for integration of functional PZT thin films on UNCD cantilevers for MEMS/NEMS applications
- Characterization of PZT/UNCD cantilevers performance
- Extend the integration to other functional materials (e.g. multiferroics) on UNCD



Schematic diagram of a molecular recognition biosensor based on PZT-UNCD heterostructured cantilever

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